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Influence of land use and land cover change on soil organic carbon and microbial activity in the forests of northern Iran

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ABSTRACT

Land-use changes can alter soil carbon (C) contents, and in particular deforestation has been responsible for a large part of the cumulative human-induced greenhouse gas (GHG) emissions. This study aimed to determine the influence of land-use and land cover change on soil organic carbon (SOC) content, microbial biomass C (MBC) and microbial respiration (MR) in the Hyrcanian forests, north of Iran. We compared an agricultural field (AF), plantations of *Alnus subcordata* (AS), *Acer velutinum* (AV), *Quercus castaneifolia* (QC) and *Cupressus sempervirens* (CS), and a natural forest (NF). Soil samples were collected at three different depths (0–20, 20–40 and 40–60 cm). Results showed that different land covers significantly affected soil characteristics, and SOC increased by 25% and 1.11% after the conversion of NF to CS and AS plantations respectively, and decreased by 4%, 12.11% and 53% when NF was converted to QC, AV and AF respectively. In all treatments, MBC and MR were significantly higher ($p < 0.05$) in the 0–20 cm depth, and MR was also correlated positively with MBC and SOC. Microbial biomass was near the half in the agriculture field than in plantations and natural forest in the upper layer, but the effects of land use on microbial biomass C decreased with soil depth. However, we observed considerable amounts microbial biomass C in 40–60 cm depth. Also, results showed that topographical feature, altitude and slope, will affect SOC content. Our results indicated that forest plantation is a key measure to enhance SOC content and mitigate global CO_2 emission, especially when soils are degraded and have low soil C content. In particular, afforestation had a crucial effect on elevating SOC content in the Hyrcanian forest, but plantations of oak (QC) and maple (AV) were less effective in terms of soil C increase.

1. Introduction

Increase in atmospheric concentrations of greenhouse gases (GHG), especially carbon dioxide (CO_2), is the primary cause of global warming. According to the Intergovernmental Panel on Climate change (IPCC, 2007), the current GHG concentrations are 30% higher than the pre-industrial level. The increasing atmospheric CO_2 concentration and the related rising global mean temperatures are threatening the earth's climate and natural habitats (Lal, 2003; IPCC, 2014).

Terrestrial ecosystems play a major role as global reservoirs of soil carbon (C) (Piao et al., 2009), and soils hold two thirds of the Earth's C (Stockmann et al., 2013).

The global C cycle is affected by the interactions among SOC, biosphere and atmosphere (Kutsch et al., 2010), and topsoils (0–30 cm depth), contain nearly half of soil organic carbon (SOC) and up to three times the C stored aboveground in vegetation. Because of land-management and climatic change, which is considered a main threat to climate (Powlson et al., 2011) topsoils are vulnerable to loss SOC as CO_2 emissions.

The spatial distribution of SOC is mainly regulated by environmental factors and anthropogenic activity (Fernández-Romero et al., 2014; Sattler et al., 2014); however, agricultural management can improve C storage either by increasing C inputs through higher crop yields or slowing its release to the atmosphere (Smith et al., 2008). Land-use change (especially deforestation) has been historically responsible for a large part of the cumulative human-induced GHG emissions (IPCC, 2007), thus affecting SOC storage that is regulated by the microbial transformations of C inputs from residues (Cramer et al., 2001;

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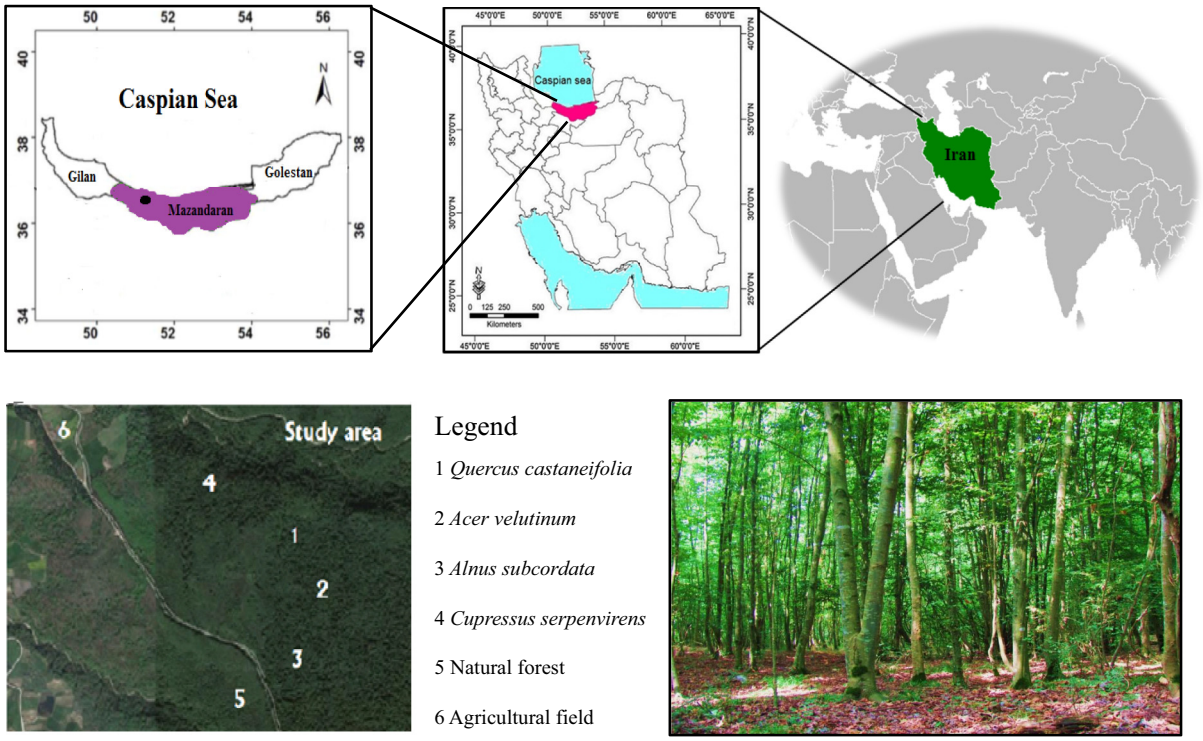

Fig. 1. Site locations of the study area in Mazandaran Province, north of Iran.

Berthelot et al., 2002; Lal, 2005; Schulp et al., 2008; Tate III, 1987). Land-use change from forest to agriculture affects both primary productivity and SOC (Murty et al., 2002; Guo and Gifford, 2002), but the effects of land cover change when a previous forest is reforested with other types of tree species are unclear, due to local conditions (e.g. soil and climate) and management factors (Rhoades et al., 2000; Kasel and Bennett, 2007).

Microbial activity regulates the decomposition of plant residues (Thoms and Gleixner, 2013), and different forest plantations provide different substrates available for microbial growth, which in turn can provide a different functioning of soil microbes (Jagadamma et al., 2014). Also, the environmental conditions under the forest canopy can affect soil respiration and microbial biomass. In this regards roots have important role and greater root system will increase subsoil C inputs and interactions with soil biota and as a result higher root turnover and rates of exudation leading to accelerated microbial activity (Williams et al., 2000; Jones and Donnelly, 2004).

The type of vegetation and land management have a significant importance on ecosystem sustainability (Carter, 2002; Dube et al., 2009), and are closely linked to SOC and soil microbial biomass and respiration (Guo and Gifford, 2002; Ross et al., 2002; Six et al., 2002; Lal, 2004; Huygens et al., 2005; Dube et al., 2009; Wang et al., 2016; Kooch et al., 2017). In addition, SOC can also be influenced by soil physical properties, thus affecting soil microbial activity (Sakin, 2014; Wang et al., 2016).

Hyrcanian forests (1.85 million ha) in the north of Iran are a well-known sink of C, but anthropogenic disturbances in these region can affect this sink (Dangal et al., 2014). Unfortunately, in the past century Hyrcanian forests have been degraded by human activity especially at lower altitudes, with remarkable changes in land use; recently reforestation was done with native and non-native species with the aim of increasing SOC contents in the more degraded regions. But there is uncertainty in the response of SOC contents to human activity, and the effectiveness of this restoration in Hyrcanian forests is not fully clear.

While other studies addressed the effect of land-use and land-use change on SOC (Haghdoost et al., 2013; Falahatkar et al., 2014; Soleimani et al., 2017), very few deal with microbial biomass and respiration in Hyrcanian forests, and did not address the effect of land-use change especially in deeper soil layers (Kooch et al., 2016; Fazlollahi et al., 2017).

The main objectives of this study were to (1) estimate SOC stocks, soil microbial biomass and respiration, (2) assess the effect of soil physical and chemical properties on SOC across soil depths (3) assess land use and land cover effects at different depths (0–20, 20–40 and 40–60 cm), and determine the differences between surface and subsoil, for different land use and land cover types, including a natural forest, four forest plantations and an agricultural field, in north of Iran.

2. Materials and methods

2.1. Site description

Darab Kola forest area is located in the southeastern part of Sari city, Mazandaran Province, Iran (latitude 36°29′19″ to 36°30′6″N, longitude 53°19′25″ to 53°19′57″ E) with an elevation between 180 and 800 m. a.s.l. (Hosseini and Jalilvand, 2007). The climate has mean monthly average temperatures ranging from 26.1 °C in August to 7.5 °C in February, with 16.7 °C on average. Mean annual rainfall is 984 mm, with minimum and maximum monthly values in July (36 mm) and November (120 mm). The main soil types are Rendzic Leptosols (IUSS Working Group WRB, 2015). Most of slopes are facing north/northeast, and average slope is 40%. The main woody species in Darab Kola forest are Oriental beech (*Fagus orientalis*), Wych elm (*Ulmus glabra*), European hornbeam (*Carpinus betulus*), Persian maple (*Acer velutinum*), Persian ironwood (*Parrotia persica*) and Black alder (*Alnus glutinosa*). Herbaceous vegetation in the forest includes sweet bedstraw (*Galium odoratum*), spurge (*Euphorbia* spp.), tutsan (*Hypericum androsaemum*) and fern (*Polystichum* spp.).

These natural forests were heavily degraded in the past years following their exploitation to meet the requirements of the local populations, and were re-afforested with new tree species by the Forest and Rangelands Organization of Iran (FROI) in 1991. The dominant forest

Table 1
Forest types properties (mean ± standard deviation) in the different land covers.

Forest type	Main species	TH (m)	DBH (cm)	Coverage (%)	Slope (%)	Altitude (m)
QC	*Quercus castaneifolia*	22.31 ± 1.90[b]	32.24 ± 7.81[b]	80	7.8	286.8
AV	*Acer velutinum*	21.60 ± 2.13[b]	28.34 ± 8.15[b]	80	5.6	299.2
AS	*Alnus subcordata*	29.92 ± 6.27[a]	41.78 ± 15.22[b]	80	7	308.2
CS	*Cupressus sempervirens*	12.94 ± 4.43[c]	35.81 ± 11.78[b]	80	6.6	305.8
AF	Wheat field	–	–	–	4.4	123.4
NF	*Parrotia persica*, *Carpinus betulus*, *Zelkova carpinifolia*	12.90 ± 6.15[c]	76.95 ± 38.17[a]	> 90	26.8	193.2

QC: oak; AV: maple; AS: alder; CS: cypress; AF: agricultural field; NF: natural forest; DBH: diameter at breast height; TH: total height.
Different letters indicate significant differences between land covers.

types, which were planted at a spacing of 2 × 2 m, included maple (*Acer velutinum* Bioss.), oak (*Quercus castaneifolia* C.A. Mey.), alder saw (*Alnus subcordata* C.A. Mey.), calabrian pine (*Pinus brutia* Tenore) and cypress (*Cupressus sempervirens* var. horizontalis). A natural forest with Persian iron wood (*Parrotia persica* C.A. Mey.), hornbeam (*Carpinus betulus* L.), elm of Siberia (*Zelkova carpinifolia* Pall.) and oak (*Quercus castaneifolia* C.A. Mey.) is also present. In this study we investigated 26 years - old plantations of maple (AV), oak (QC), alder (AS) and cypress (CS), as well as a natural forest stand (NF) and an agricultural field (wheat field) (AF) near the afforested stands (Fig. 1). The vegetation information of the different forest land covers is shown in Table 1.

2.2. Data collection

In November 2015, after the end of the growing season, soil samples were taken at 0–20 cm, 20–40 cm and 40–60 cm depths. Five sampling quadrats (with regular shape, 5 × 5 m) were established in each land-use type, maple (AV, 15 ha), oak (QC, 20 ha), alder (AS, 7 ha) and cypress (CS, 4 ha), natural forest stand (NF, 10 ha) and an agricultural field (AF, 4 ha). Soil samples were taken from four corners of square (trying to 1 m distance from the trees) and mixed to form a composite sample for each depth. Coarse live plant material (root and shoots) in each sample was hand removed in the laboratory and discarded. Soil samples were air-dried and sieved (2 mm mesh). Soil texture was determined using the hydrometer method (Day, 1965). Soil reaction was determined using a pH meter in a 1:2.5, soil:water solution, total organic C by the Walkley-Black and total N by the Kjeldahl methods (Walkley and Black, 1934; Kjeldahl, 1883 respectively). Bulk density was measured by the clod method (Plaster, 1985).

Soil OC (Ponce-Hernandez et al., 2004) and STN stocks (soil total nitrogen) (Chen et al., 2007) for each depth were calculated with the formulas:

$$SOC = C\,(\%) \times BD \times d \quad (1)$$

$$STN = N\,(\%) \times BD \times d \quad (2)$$

where SOC indicates the organic C stock ($t\,C\,ha^{-1}$); STN indicates the soil total nitrogen ($t\,N\,ha^{-1}$); C is the percentage of organic C content; N is the percentage of nitrogen; BD is the bulk density ($g\,cm^{-3}$); d is thickness (cm).

Available P was determined using the Olsen method with a spectrophotometer (Homer and Pratt, 1961), and exchangeable K with an atomic absorption spectrophotometer (Bower et al., 1952).

To measure soil respiration (MR) and soil microbial biomass C (MBC), the collected fresh soils were kept at 4 °C until analyses. Soil microbial respiration was determined by trapping the CO_2 evolved over a 3 day incubation at 25 °C in a 0.05 M NaOH solution, and titrating against 0.1 M HCl (Alef, 1995). Soil microbial biomass C was determined using the chloroform fumigation-extraction method (Brookes et al., 1985; Vance et al., 1987).

Also, an inventory of the natural forest and the four plantations was performed. Five sampling quadrats were randomly established in each land covers, with regular shape and dimensions (10 × 10 m). Diameter at breast height (DBH) was measured with a caliper, and total height (TH) of all the trees with Suunto clinometers.

2.3. Statistical analyses

The effects of land cover and soil depth, as well as their interaction, were tested using a two-way ANOVA (Chambers et al., 1992). The Duncan multiple comparisons were performed to test and display the 95% family-wise confidence level of simultaneous pairwise difference. Pearson's product moment coefficient was generated to test the correlation among the parameters (R function 'rcorr'). Also a PCA (principal component analysis) was performed on soil parameter data across different land use (R commander). All statistical analyses were performed using the R statistical software (R Core Team, 2013).

3. Results

3.1. Soil physical and chemical characteristics

The results indicated that land cover and soil depth influenced most of the soil characteristics analyzed. All soil parameters considered (bulk density, silt, clay, sand, pH, C, N, C/N ratio, available P and exchangeable K) showed significant differences among land uses and/or soil depths (Table 2). In addition, significant interactions between land cover and soil depth were observed for bulk density, C, N, C/N ratio, exchangeable K and available P (Table 2).

Soil characteristics across land uses and soil depths are reported in Fig. 2. Soil bulk density in the natural forest and the agricultural field showed significantly higher values when compared with the other treatments, and values significantly increased with depth ($p < 0.001$) (Fig. 2a). Sand, clay and silt were slightly significantly different among land uses (Fig. 2b, c, d), the agriculture field had higher content of clay and the natural forest the higher content of silt and sand. Soil pH was higher in the natural forest compared to the other land uses, and tended to increase with depth (Fig. 2e).

Organic C values decreased with soil depth, and a significantly higher value was found under the cypress plantation compared with the other land uses ($p < 0.001$). The agricultural field showed the lowest organic C level (Fig. 2f).

Total N was significantly higher under the alder plantation when compared with the other land uses ($p < 0.01$) (Fig. 2g), while higher values of the C/N ratio were found under the cypress plantation ($p < 0.01$) (Fig. 2h). Total N contents and C/N ratio decreased with soil depth.

There were significant differences ($p < 0.01$) in available P, with the highest contents under the alder plantation and the lowest for the agricultural field and the cypress plantation (Fig. 2i). Exchangeable K was significantly ($p < 0.01$) higher in the alder plantation when compared with the other land uses, and the lowest value was found in the agricultural field (Fig. 2j).

Table 2
Results of two-way ANOVA for soil characteristics in the different land uses and soil depth.

Sources	Physical characteristics				Chemical characteristics									
	BD (g cm^{-3})	Sand (%)	Silt (%)	Clay (%)	pH	C (%)	N (%)	C/N	Available P (mg kg^{-1})	Exchangeable K (mg kg^{-1})	MR (mg kg^{-1})	SOC (t C ha^{-1})	MBC (mg kg^{-1})	STN (t ha^{-1})
Land cover (A)	21.15***	3.54***	1.36	3.22*	3.99**	51.26***	12.43***	22.45***	29.95***	37.54***	9.51***	43.74***	16.72***	11.97***
Depth (B)	122.09***	10.40***	52.41***	28.85***	2.91	279.2***	67.67***	5.24**	27.22***	24.76***	8.25***	212.75***	76.28***	47.57***
Interaction A * B	3.09**	1.68	1.16	0.93	0.87	3.01**	5.19***	2.59**	1.98*	2.37*	1.95	1.97*	1.35	5.07***

Values represent F values.
BD: bulk density; C (%): carbon; N (%): nitrogen; C/N: C:N ratio; MR: microbial respiration; SOC: soil organic carbon stock; MBC: microbial biomass carbon; STN: soil total nitrogen.
* $p(F) < 0.05$.
** $p(F) < 0.01$.
*** $p(F) < 0.001$.

3.2. Soil organic carbon and total nitrogen stocks

Cypress plantation (CS) had the highest SOC stocks among the different land uses. Soil OC stocks at 0–60 cm depth decreased in the order CS > AS > NF > QC > AV > AF (Fig. 2k). Soil OC was significantly lower in the agricultural field compared with the plantations and the natural forest ($p < 0.01$). Soil OC stocks increased by 25% and 1.1% following the conversion of NF to CS and AS plantations respectively, while decreased by 4%, 12% and 53% with the conversion from NF to QC, AV and agricultural field respectively. Average SOC stock at 0–20 cm depth represented about half the total SOC stock at 0–60 cm depth.

Soil total nitrogen stocks STN were significantly different in land uses and also decreased with soil depth ($p < 0.01$) (Fig. 2l). The highest STN stocks were found in AS (22.68 t N ha^{-1}), the lowest in CS (11.09 t N ha^{-1}), and decreased in the order AS > NF > AV > AF > QC > CS (Fig. 2l). Soil TN was significantly higher in the 0–20 cm depth compared with the 20–40 and 40–60 cm depth, while no significant difference was found between 20 and 40 and 40–60 cm depth. Along soil depths, average STN stock decreased from 7.49 t N ha^{-1} (0–20 cm) to 3.68 t N ha^{-1} at the 40–60 cm depth. Similarly to SOC, STN stock in the 0–20 layer was about half the amount in the total depth (0–60 cm).

3.3. Soil microbial respiration and microbial biomass carbon

Microbial soil respiration (MR) was significantly different among land use types ($p < 0.001$), with the highest values in the natural forest, and the lowest in the maple plantation (AV) and the agricultural field (AF), in the order NF > CS > AS + QC > AV > AF. Fig. 2m shows that the MR decreased with soil depths, was significantly higher in the 0–20 cm soil depth ($p < 0.001$). Soil microbial biomass C was affected significantly by land-use and decreased in the order CS > AS > NF > QC > AV > AF (Fig. 2n), and varied significantly with depth ($p < 0.001$). Higher MBC was found in 0–20 cm depth. The highest microbial biomass C at 0–20 cm depths corresponded also to the higher SOC values found at this depth.

3.4. Correlation and principal component analysis

Significant correlation coefficients were found among some of the characteristics (Table 3). Positive and significant correlations were found between bulk density and clay ($r = 0.53$, $p < 0.01$). Conversely, bulk density was negatively correlated with C, SOC stocks and MBC. Clay and silt were strongly and negatively correlated ($r = -0.75$, $p < 0.01$).

Significant correlations between organic C and most soil characteristics were observed, in particular with SOC stocks, MBC, and BD ($r = 0.99$, 0.82 and −0.83 respectively, $p < 0.01$). Total N had a positive correlation with exchangeable K SOC and STN.

Soil OC stocks (Table 3) were significantly correlated with all the other soil characteristics, except sand ($p < 0.01$), and highly positive correlations were found with organic C and microbial biomass C ($r = 0.99$ and 0.81 respectively, $p < 0.01$).

Soil TN stocks were significantly correlated with soil characteristics (Table 3), except sand, pH and microbial respiration, and the highest positive correlations was found with exchangeable K ($r = 0.60$, $p < 0.01$).

According to Table 3, most soil characteristics showed significant correlations with MR, and the highest and positive correlation was found with microbial biomass C ($r = 0.62$, $p < 0.01$).

Soil microbial biomass C had positive correlation (Table 3) with organic C ($r = 0.82$, $p < 0.01$), microbial respiration ($r = 0.62$, $p < 0.01$) and SOC stocks ($r = 0.81$, $p < 0.01$).

The results of correlations between soil parameter and DBH and TH of forest land covers are presented in Table 4. Diameter BH had highest

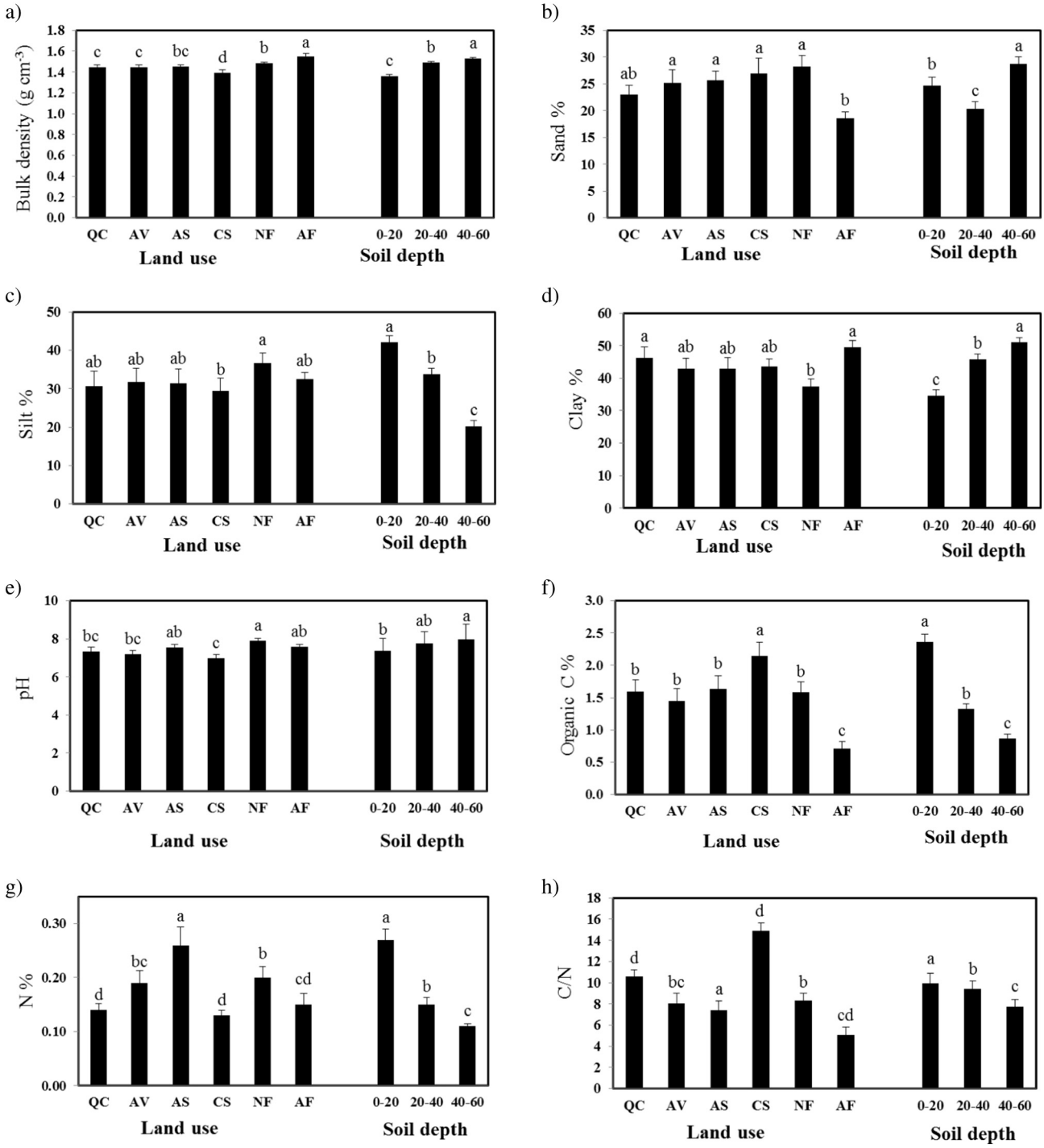

Fig. 2. Mean values of soil characteristics across the different land uses, and soil depths.
QC: *Quercus castaneifolia*; AV: *Acer velutinum*; AS: *Alnus subcordata*; CS: *Cupressus sempervirens*; NF: natural forest; AF: agricultural field; SOC: soil organic carbon stock; STN: soil total nitrogen stock; MR: microbial respiration; MBC: microbial biomass carbon.
Different letters indicate significant differences between land uses, and soil depths.

correlation with MR ($p < 0.01$) but TH had highest correlation with available P ($p < 0.01$).

A PCA (Principal Component Analysis) was performed on soil parameters under the studied land uses (Fig. 3). The first component (PC1) explained 43.05%, and the second (PC2) explained 16.89% of variance. The right PC1 presented a good condition of macro elements, SOC, total nitrogen and microbial activity that is related to NF, AV, CS and AS plantations, while the left PC1 were related to QC and AF with opposite soil conditions. The positive part of PC2 indicated similar conditions of macro elements and total nitrogen linked with AF, AS, AV and NF land uses. The negative part of PC2 showed similarities among SOC, C/N ratio, microbial biomass C and microbial respiration, associated with CS and QC land uses.

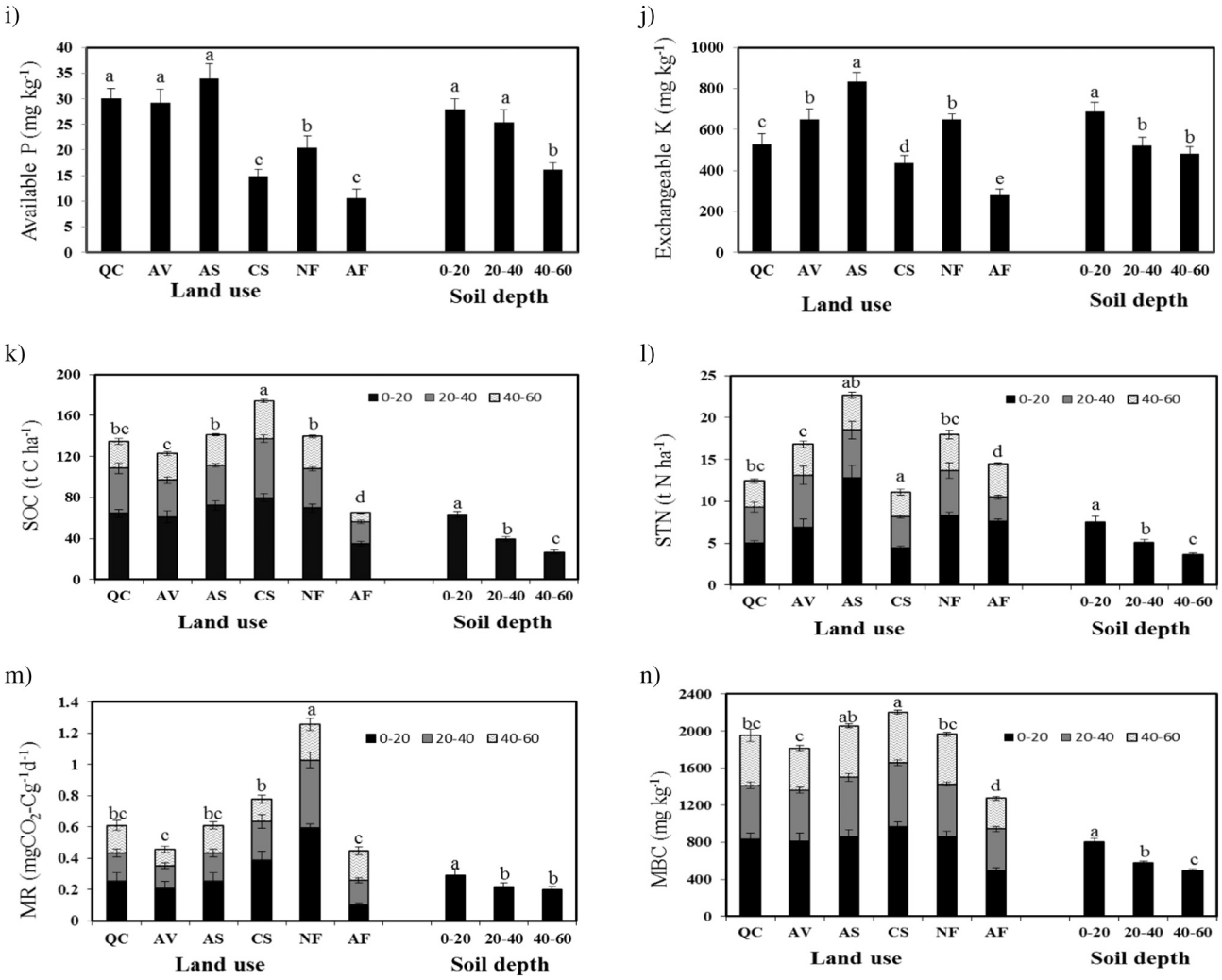

Fig. 2. (*continued*)

4. Discussion

4.1. Soil physical and chemical characteristics

Soil bulk density showed significantly ($p < 0.01$) higher content in AF compared with the other land uses, and presented an opposite trend with depth compared to organic C (%). These results are in agreement with previous studies (Li et al., 2013; Zhang et al., 2014; Francaviglia et al., 2017a). Higher BD values in deeper layers of forest soils are due to the weight of the overlying horizons (Grüneberg et al., 2014), and have been indicated by different researches (Grüneberg et al., 2014; Schrumpf et al., 2011; Parras-Alcántara and Lozano-García, 2014).

Our results indicated that clay, silt and sand contents depend to the land use and soil depth; similarly Yuksek and Yuksek (2011) stated different land use has different clay and sand percentages, and bare land had the highest content of sand while black locust plantation had the lowest content. In opposite Evrendilek et al. (2004) and Korkanç (2014) indicated that no significant difference was found among land use and soil depths in relation to soil texture (sand, silt and clay contents).

The highest values of organic C (%) were in the CS plantation, and the lowest value was found in AF, and PCA results confirmed this situation. Chase and Singh (2014) reported that soil organic matter has rapid mineralization in areas with high pH and as a result organic C will decrease. In our study organic carbon had a significant correlation with soil N that we observe this trend in research of Kooch et al. (2014). Organic C was overall positively correlated with microbial respiration and microbial biomass C, and its content significantly decreased with depth.

The highest and lowest amounts of soil N was found in AS and CS respectively, and can be related to the higher depletion of soil N in coniferous species in comparison with broad leaves (Inagaki et al., 2004). Rothe et al. (2002) also stated that the existence of N-fixing species in forest plantations, e.g. AS in our study, might increase soil total N content.

Decreasing contents of available P and K were found with increasing soil depths. In the soils with lower pH, soil organic matter mineralization is lower, clay particles lose their capacity to absorb base cations, and consequently soil nutrient contents are not high (Nsabimana et al., 2008). Moreover, at lower pH soil P is more immobilized (Chase and Singh, 2014), as in the case of the low available P in CS in this research. *Alnus subcordata* (AS) had higher contents of available P and K, that may be related to a faster soil nutrients cycling, helping to preserve higher soil contents of P and K (Chase and Singh, 2014). In general, coniferous species in comparison with deciduous species had a higher C/N ratio, lower nutrient contents and lower pH (Kooch et al., 2016).

Nutrient contents significantly increased after the conversion of the natural forest to the plantations, in agreement with Haghdoost et al. (2011), but under CS plantation soil K and P were lower compared to the natural forest, and under QC plantation soil exchangeable K was lower than in the natural forest. Also we found positive correlations

Table 3
Pearson's correlation coefficients among the soil characteristics.

	BD (g cm^{-3})	Sand (%)	Silt (%)	Clay (%)	pH	C (%)	N (%)	C/N	Available P (mg kg^{-1})	Exchangeable K (mg kg^{-1})	MR (mg kg^{-1})	SOC (t C ha^{-1})	MBC (mg kg^{-1})	STN (t N ha^{-1})
BD (g cm^{-3})	1													
Sand (%)	−0.01	1												
Silt (%)	−0.48**	−0.37**	1											
Clay (%)	0.53**	−0.30**	−0.75**	1										
pH	0.27**	0.15	−0.018	−0.02	1									
C (%)	−0.83**	0.05	0.51**	−0.57**	−0.31**	1								
N (%)	−0.38**	0.01	0.43**	−0.44**	−0.18	0.48**	1							
C/N	−0.53**	0.07	0.08	−0.17	−0.16	0.57**	−0.35**	1						
Available P (mg kg^{-1})	−0.39**	−0.10	0.28**	−0.25*	−0.14	0.39**	0.46**	0.009	1					
Exchangeable K (mg kg^{-1})	−0.36**	0.05	0.35**	−0.40**	−0.15	0.44**	0.61**	−0.04	0.52**	1				
MR (mg kg^{-1})	−0.21*	0.05	0.35**	−0.34**	−0.001	0.40**	0.16	0.20	−0.02	0.17	1			
SOC (t C ha^{-1})	−0.77**	0.07	0.50**	−0.57**	−0.30**	0.99**	0.50**	0.55**	0.40**	0.48**	0.42**	1		
MBC (mg kg^{-1})	−0.71**	0.07	0.49**	−0.56**	−0.19	0.82**	0.43**	0.46**	0.33**	0.47**	0.62**	0.81**	1	
STN (t N ha^{-1})	−0.27**	0.02	0.40**	−0.40**	−0.15	0.40**	0.99**	−0.43**	0.44**	0.60**	0.15	0.43**	0.37**	1

Values represent the Pearson's correlation coefficients.
BD: bulk density; C (%): carbon; N (%): nitrogen; C/N: C:N ratio; MR: microbial respiration; SOC: soil organic carbon stock; MBC: microbial biomass carbon; STN: soil total nitrogen.
* $p < 0.05$.
** $p < 0.01$.

Table 4
Pearson's correlation coefficients among soil and forest characteristics.

	BD (g cm^{-3})	Sand (%)	Silt (%)	Clay (%)	pH	C (%)	N (%)	C/N	Available P (mg kg^{-1})	Exchangeable K (mg kg^{-1})	MR (mg kg^{-1})	SOC (t C ha^{-1})	MBC (mg kg^{-1})	STN (t N ha^{-1})
DBH (cm)	0.21	0.03	0.11	0.12	0.27*	−0.08	0.11	−0.22	−0.14	0.12	0.33**	−0.04	−0.01	0.14
TH (m)	0.15	−0.14	−0.07	0.13	0.02	−0.22	0.15	−0.31**	0.48**	0.31**	−0.35**	−0.22	−0.13	0.17

Values represent the Pearson's correlation coefficients.
BD: bulk density; C (%): carbon; N (%): nitrogen; C/N: C:N ratio; MR: microbial respiration; SOC: soil organic carbon stock; MBC: microbial biomass carbon; STN: soil total nitrogen; DBH: diameter at breast height; TH: total height.
* $p < 0.05$.
** $p < 0.01$.

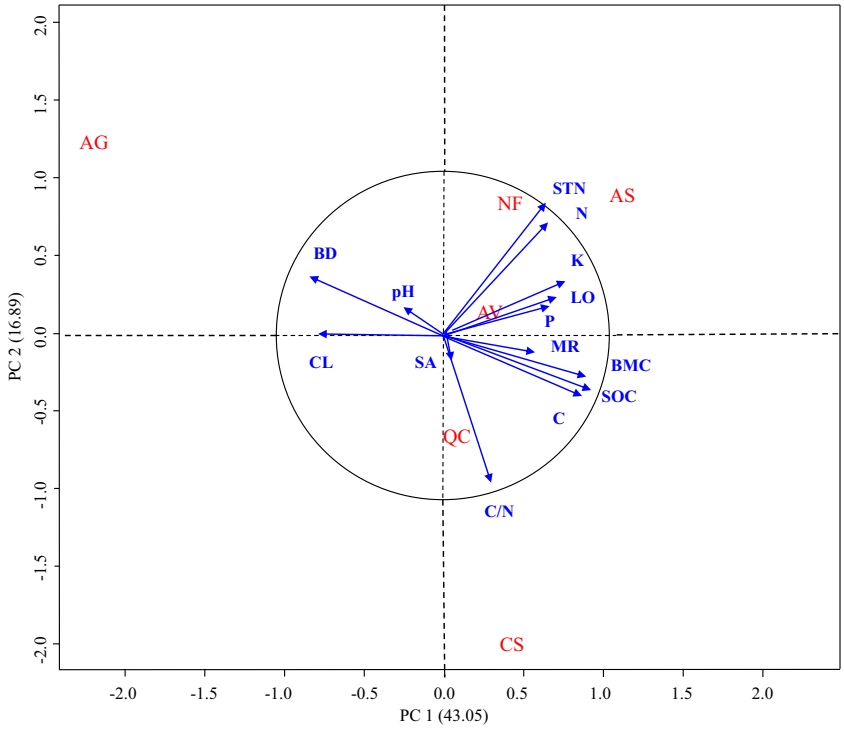

Fig. 3. PCA of soil parameter, altitude and slope.
BD: bulk density; C (%): carbon; N (%): nitrogen; C/N: C:N ratio; MR: microbial respiration; SOC: soil organic carbon stock; MBC: microbial biomass carbon; STN: soil total nitrogen; CL: clay; LO: silt; SA: sand; SL: slope; AL: altitude. QC: *Quercus castaneifolia*; AV: *Acer velutinum*; AS: *Alnus subcordata*; CS: *Cupressus sempervirens*; NF: natural forest; AF: agricultural field.

between height and available P and exchangeable K, indicating that these soil chemical properties have a stronger influence on forest height than soil physical properties. These results are opposite the results of Alijanpour et al. (2014).

4.2. SOC concentration and N stocks across land uses

Soil OC varies with the type of land use, and changes are extremely complex (C. Zhang et al., 2013). Soils with different vegetation covers have different litter decomposition processes leading to a difference in the release of C to soil (C. Zhang et al., 2013). In this study, the results showed that land-use types had significant effects on SOC. In addition, our results showed a SOC decrease with the increase of soil depth in all the land uses, in agreement with other research (Jobbágy and Jackson, 2000; Shi et al., 2013; Dorji et al., 2014; Parras-Alcántara et al., 2015; Wang et al., 2016; Francaviglia et al., 2017b; C. Zhang et al., 2013).

In this study SOC stock of the agricultural field was about 50% lower compared to the natural forest in the surface layer (0–20 cm), in agreement with Jafarian and Kavian (2013), Gelaw et al. (2014), and Wang et al. (2016). In this regards Abera and Belachew (2011) in southeastern Ethiopia founded that forest soils have twice value of C contents than arable soils. Also Bárcena et al. (2014) stated that the higher SOC in forests derives from higher surface litter input compared to cultivated land. In study Rasouli-Sadaghiani et al. (2018) compared different land use in West Azerbaijan, Iran and their results showed SOC decline by 36.3% in grassland, 43.6% in orchard land, 67.7% in arable land compared with forestland. The amounts of SOC in the agricultural field were the lowest compared with the plantations and the natural forest, with CS having the highest SOC stock, confirming that converting forests to agriculture can decreases SOC stocks.

In addition, SOC will affect the different soil properties and the decomposition rate in different land uses (Jafarian and Kavian, 2013). Results showed that bulk density had negative correlation with SOC in trend as observed in Korkanç, 2014 study. In particular, SOC stock was higher in cypress plantation and bulk density was lower; conversely, SOC stock was lower and bulk density higher in the agricultural field. At lower soil bulk density, SOC can increase since organic C can be more efficiently mobilized within the soil matrix (Anh et al., 2014).

There is a contrasted opinion about the relationship between SOC and clay content. Some studies indicated that soil clay provides a physical protection to organic C against microbial decomposition (Six and Paustian, 2014). Other authors suggest that high clay values promote the decomposition of fresh organic matter due to higher substrate availability and microbial biomass (Wei et al., 2014; Montes-Pulido et al., 2017). According to our results, clay values were significantly different among land uses ($p < 0.01$), and negatively correlated with SOC ($p < 0.01$), in agreement with other research. Parras-Alcántara et al. (2015) reported a significant negative correlation between clay and SOC ($p < 0.05$) in Mediterranean Leptosols under a high density *Quercus ilex* land cover. Montes-Pulido et al. (2017) found a strong negative correlation ($p < 0.001$) in cropped and natural ecosystems of the tropical northern Andean mountains in Colombia. In contrast Willaarts et al. (2016) stated that clay highly correlated to SOC ($r^2 = 0.7523$; $p < 0.05$). Also Traoré et al. (2015) stated in bulk soil there was not significant correlation between clay and C while in native land cover category there was a strong positive correlation between them.

Many researches have documented the correlation between SOC and N stock (Li et al., 2012; Deng et al., 2013; Deng et al., 2016) our results also showed this relation.

Different vegetation has different litter quality leading to the different STN (Z.S. Zhang et al., 2013). Also Mueller et al., 2012 reported that different tree species impact on retention of soil N. AS and AV and NF had higher STN than the agricultural field AF, as already reported by other authors (Jafarian and Kavian, 2013; Gelaw et al., 2014; Wang et al., 2016). Bárcena et al. (2014) indicated that forests have more litter inputs and SOC than cultivated land, and this may result in higher STN.

Cupressus sempervirens (CS) had higher C/N ratio, probably due to low mineralization rates and, consequently, to the low amounts of total N and available nutrients (Haghdoost et al., 2011). Other researches showed that coniferous stands had higher C/N ratio and lower nutrient content in comparison with deciduous stands (Rostamabadi et al., 2013; Kooch et al., 2016). In addition, low C/N ratio is naturally associated with fine soil fractions at deeper depths (Gerzabek et al., 2006).

4.3. Soil microbial respiration and microbial biomass carbon

In the long term, trees in forests ecosystems can continually add litter and increase root turnover, therefore can maintain or increase soil organic matter (Kimmins, 2004), and may influence soil microbial respiration. Mallik and Hu (1997) stated that soil organic matter is strongly related to soil microbial respiration, and is one of the main parameters controlling it. In this study the results showed that soil microbial respiration (MR) was significantly different both among land uses and soil depths ($p < 0.001$).

The highest MR was found at 0–20 cm depth, and might result from the higher microbial biomass C, SOC and the associated SOC stocks (Dube et al., 2009). Moreover, the highest soil MR was observed in the natural forest, and the agricultural field had the lowest respiration. Saggar et al. (2001) stated that soil microbial respiration will increase with higher values of SOC due to the dependence of soil microbial activity on the supply of a C substrate. Bayranvand et al. (2017); Fazlollahi et al. (2017) and Kooch et al. (2014) stated there is a strong positive correlation between microbial respiration and OC.

In NF, the higher MR at 0–20 cm depth could be related to the high content of microbial biomass at this depth, which was significantly higher than at the other depths. In contrast, the lowest values of soil MR were observed in 40–60 cm depth where less organic C was present.

The microbial biomass C (MBC) was significantly higher in the CS and AS plantations compared to QS and AV plantations, NF and the agricultural field. Due to difference in agricultural practices, resource availability and plant composition, MBC will generally decrease in agricultural fields (Six et al., 2006; Van Leeuwen et al., 2017). Agricultural field had the lowest MBC, and this finding is similar to those from Bardgett (2005) and Six et al. (2006). Islam and Weil (2000) reported that the MBC was about 40% lower in agricultural soils compared to natural forests. Thus, the conversion of native forests to agricultural lands not only strongly affects physical and chemical soil attributes, but also the soil microbial community associated with C cycling (Pabst et al., 2013). In another study Rasouli-Sadaghiani et al. (2018) reported in long-term land use and deforestation had adverse effects on MBC and MBC declined by an average of 34.8% compared with forestland in West Azerbaijan, Iran.

Soil C are introduced key ecological driving factors for MBC (Fierer et al., 2009), and in our study high and significant correlations of MBC were found with organic C and C/N ratio. In this regards our results are agree with Fazlollahi et al. (2017).

Hassett and Zak (2005) stated that increased MBC was driven by increased litter inputs. Wu et al. (2016) found higher microbial biomass in afforested soils compared with open areas, croplands and shrublands, thus forests can exhibit higher microbially derived necromass, decomposition products and metabolites (Leff et al., 2012), which can increase the stability of SOM (Schmidt et al., 2011; Gunina et al., 2014). Microbial biomass C was about the half in the agriculture field compared to the other land use in the surface layer, but this difference was lower in the subsoil indicating that the effects of land use on microbial biomass C decreases with depth, as shown by Van Leeuwen et al. (2017). The observed decrease of MBC with soil depth (Taylor et al., 2002; Fierer et al., 2003) may be due to the lower C and N contents in the subsoil. However, there was a considerable microbial biomass C in the 40–60 cm depth.

In general our results showed land use and land cover change can change soil properties. Agricultural field had lowest SOC, MR and MBC compared with natural forest. Loss of these factors in agricultural field can be due to cultivation, soil erosion, poor management, plowing and soil tillage. So suitable management practices, return of crop residues to the soil and use of agroforestry system can help to improve these areas.

Also After conversion natural forest to plantations depending on species, soil conditions improved. In this study *Alnus subcordata* and *Cupressus sempervirens* plantations increased SOC and are a good select and if we apply of multicultural we can have more sustainable forests.

5. Conclusions

Our results demonstrated that the type of forest trees had different significant effects on soil properties and microbial activity. Many studies on soil microbial activity are conducted in the upper layer or topsoil, because the main changes after the conversion among land uses are expected in the upper depths, whereas subsoils are mostly less studied. Results suggested that land use change had higher effects on the microbial activity in the surface layer than in deeper depths, but indicated a considerable microbial biomass C in the 40–60 cm depth.

Afforestation with new plantations was effective in increasing SOC contents and can enhance microbial biomass C compared to the natural forest, but oak and maple were less effective in terms of soil C increase. Also, our results showed that topography can have an effective influence on SOC content. The N-fixing species (alder trees) enhanced soil fertility (higher amounts of available nutrients including P and K) compared to cypress, maple and oak species. Microbial biomass C was significantly higher in cypress and lower in the agricultural field. The different quality of available substrates and the distribution of C inputs in soil in the different land uses are a possible explanation. Concerning soil microbial respiration, it correlates positively with MBC and SOC, but it did not discriminate their contribution to soil respiration in land uses.

Half of SOC content in agriculture field is concentrated in 0–20 cm of soil so human disturbance (e.g. soil tillage) can decrease soil C stocks. Thus, a rational and suitable agricultural land use is very important for C sequestration. Topsoil showed more significant differences than subsoil in relation to SOC and STN. We can conclude that the adoption of forest restoration of natural degraded forests with the plantation of suitable species has a great potential in terms of C sequestration and soil microbial activity.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.catena.2019.02.018.

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